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Thermodynamic and magnetic properties of the confined neutral Fermi systems

D.A. Tayurskii[a,b,*], A.R. Minnullin[a]

[a] Physics Department, Kazan State University, Kazan 420008, Russia
[b] Physics Department, Kanazawa University, Kanazawa 920-1192, Russia

Abstract

The heat capacity and magnetic susceptibility of free Fermi systems confined to spherical pores and to 2D circles are studied theoretically. It is shown that taking into account the existence of a pore size distribution leads to the smoothing of magnetic susceptibility oscillations. The areal density dependencies of the heat capacity and magnetic susceptibility of the free 2D Fermi gas are obtained.

Keywords: Neutral Fermi system; Confined geometry; ^{3}He–^{4}He films; Magnetic susceptibility

1. Introduction

As it was shown in Ref. [1] the geometrical confinement can lead to the appearance of some quantum size effects even for free Fermi systems. The examples of the confined Fermi systems are liquid or gaseous ^{3}He in porous substances (see, for example, Ref. [2]), in aerogels [3,4], the "puddles" of liquid ^{3}He in ^{3}He–^{4}He thin films [5], ^{3}He nano-clusters embedded into a ^{4}He matrix [6,7], etc. As far as even a free confined Fermi system shows new physical features due to the discreteness of spectrum [1], it seems reasonable to investigate the properties of a neutral free Fermi system being in the confined geometry in more detail before considering the more realistic systems such as normal and superfluid liquid ^{3}He and ^{3}He–^{4}He mixtures.

2. The influence of pore size distribution

The oscillations of magnetic susceptibility in dependence on the size of geometrical confinement and particle density have been predicted in Ref. [1]. Namely, such oscillations have to appear, for example, in ^{3}He–^{4}He mixtures confined to spherical pores of radius R (or cylindrical ones) when one changes the ^{3}He concentration. But it was unclear whether this effect is observable in experiment or not because some distribution of pore sizes should exist in a real substance (for example, Vycor glass). Fig. 1 shows the damping of such oscillations at different values of the width of pore size distribution of Gaussian type σ:

$$P(r) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(r - R_0)^2}{2\sigma^2}\right), \tag{1}$$

where $P(r)$ denotes the probability of the finding the spherical pore with radius r and R_0 being the mean value of spherical pore radius. It follows also from our calculations that at given values R_0 and σ, the oscillations become more pronounced with the temperature lowering (see Fig. 2). Such a feature believes to be caused by the fact that at temperatures well below Fermi temperature T_F the main contribution to the magnetic susceptibility comes from particles distributed just near Fermi level the position of which depends strongly on the geometrical confinement size and particle density. Note also that relative amplitude of magnetic susceptibility oscillations becomes almost constant at temperatures below 0.01 K.

*Corresponding author. Present address: Physics Department, Kanazawa University, 920-1192 Kanazawa, Russia.
E-mail address: dtayursk@mi.ru (D.A. Tayurskii).

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